The NOνA Experiment
(NuMI Off-Axis ν_e Appearance Experiment)

- NOνA is an approved Fermilab experiment optimized for measuring ν_e appearance with the goal of improving MINOS's $\nu_\mu \rightarrow \nu_e$ measurement by approximately an order of magnitude.
- The NOνA far detector will be
  - a 30 kT "totally active" liquid scintillator detector
  - located ~15 mrad (12 km) off the NuMI beamline axis near Ash River, MN, 810 km from Fermilab
- The uniqueness of NOνA is the long baseline, which is necessary for determining the mass ordering of the neutrino states

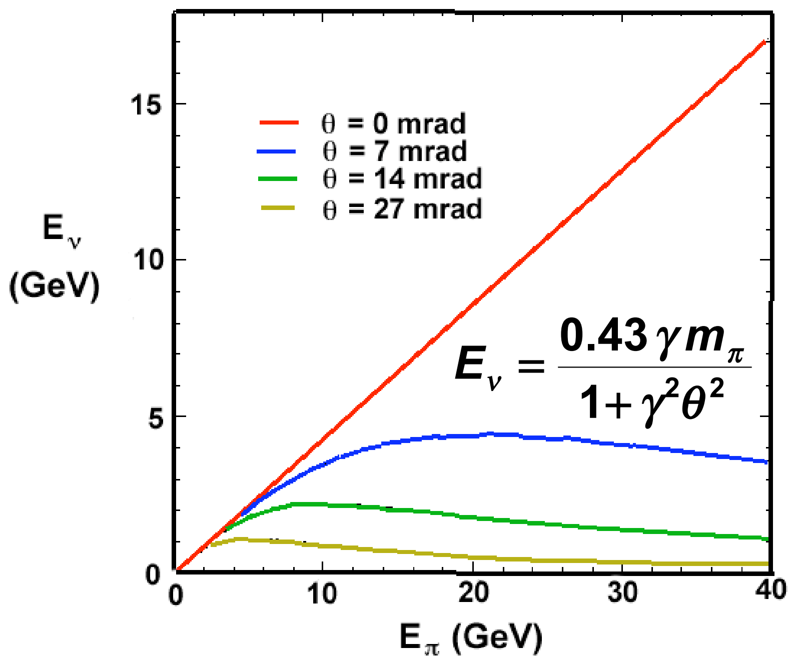
[Thanks to Gary Feldman for many slides]

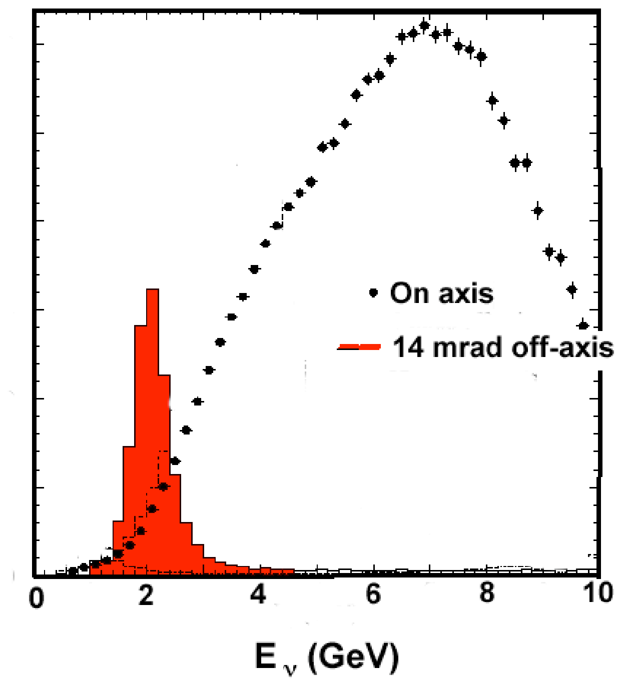
Points to Consider

- Depending on the values of as yet either not well known or unknown parameters, elucidating the lepton sector (mixing parameters, mass hierarchy order, CP violation) will likely range from just hard to nearly impossible
- Both neutrino and antineutrino beams and multiple distance scales may well be necessary
- Much about NOνA, including the exact detector location will depend on better knowledge of Δm^2_{23}
- MINOS experiment is running very well and approaching 10^{20} protons on target

Off-Axis Rationale

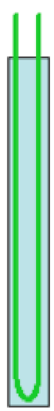
- Both NOνA and T2K are sited off the neutrino beam axis. This yields a narrow band beam:
  - More flux and less background (ν_e's from *K* decay and higher-energy NC events)

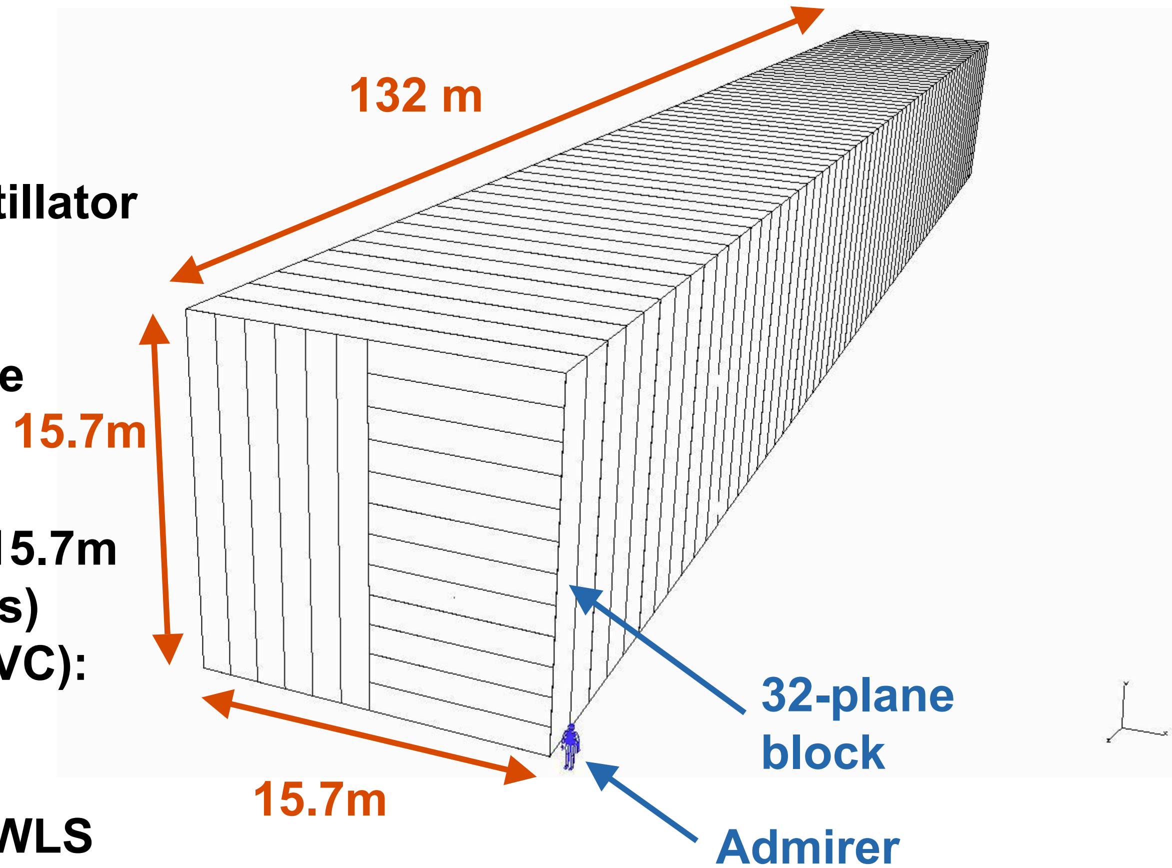




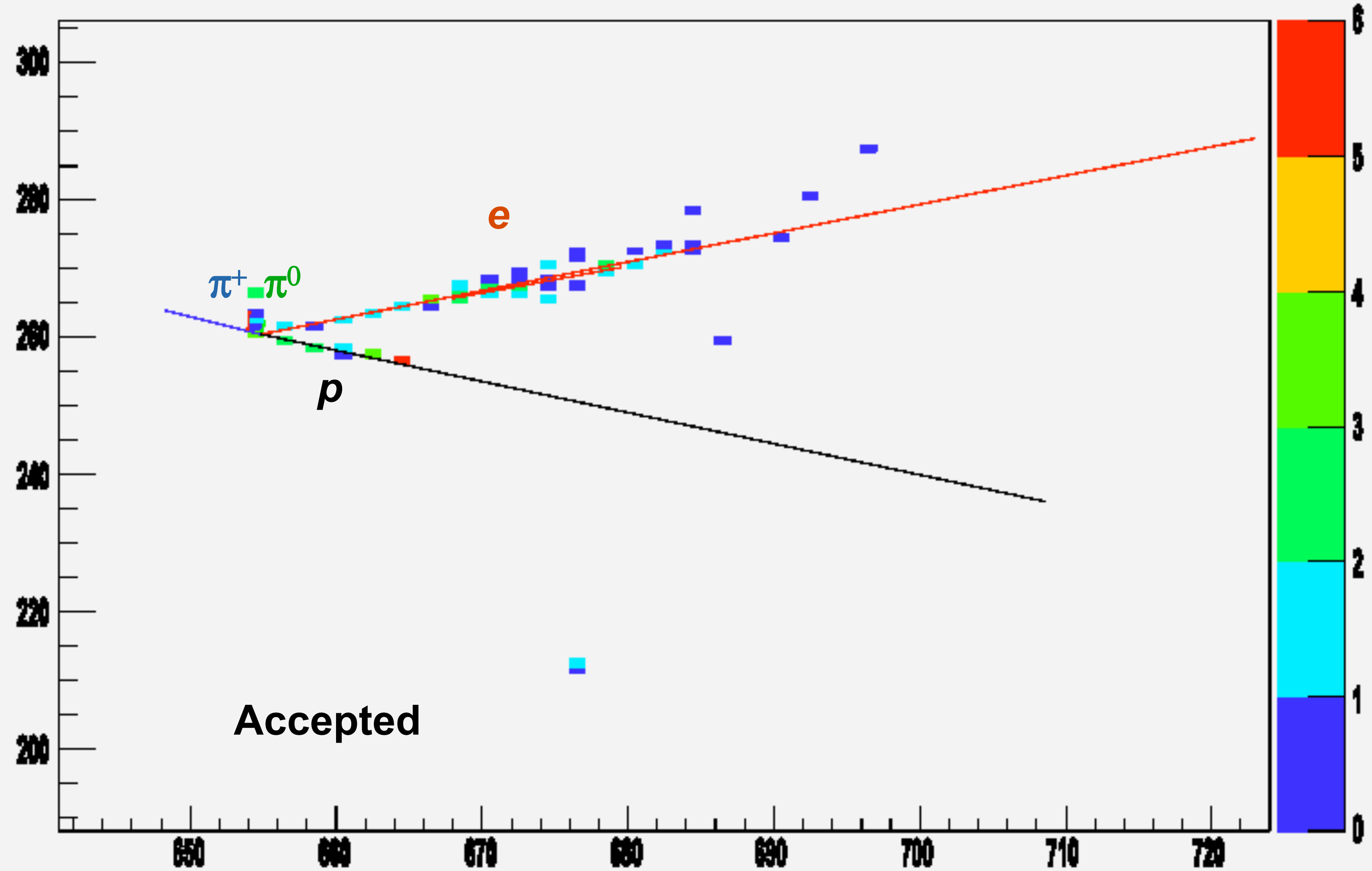
NOνA Far Detector

"Totally Active"
30 kT:
 24 kT liquid scintillator
 6 kT PVC
32 cells/extrusion
12 extrusions/plane
1984 planes
Cell dimensions:
 3.9 cm x 6 cm x 15.7m
 (0.15 X_0 thickness)
Extrusion walls (PVC):
 3 mm outer
 2 mm inner
U-shaped 0.8 mm WLS
fiber into APD

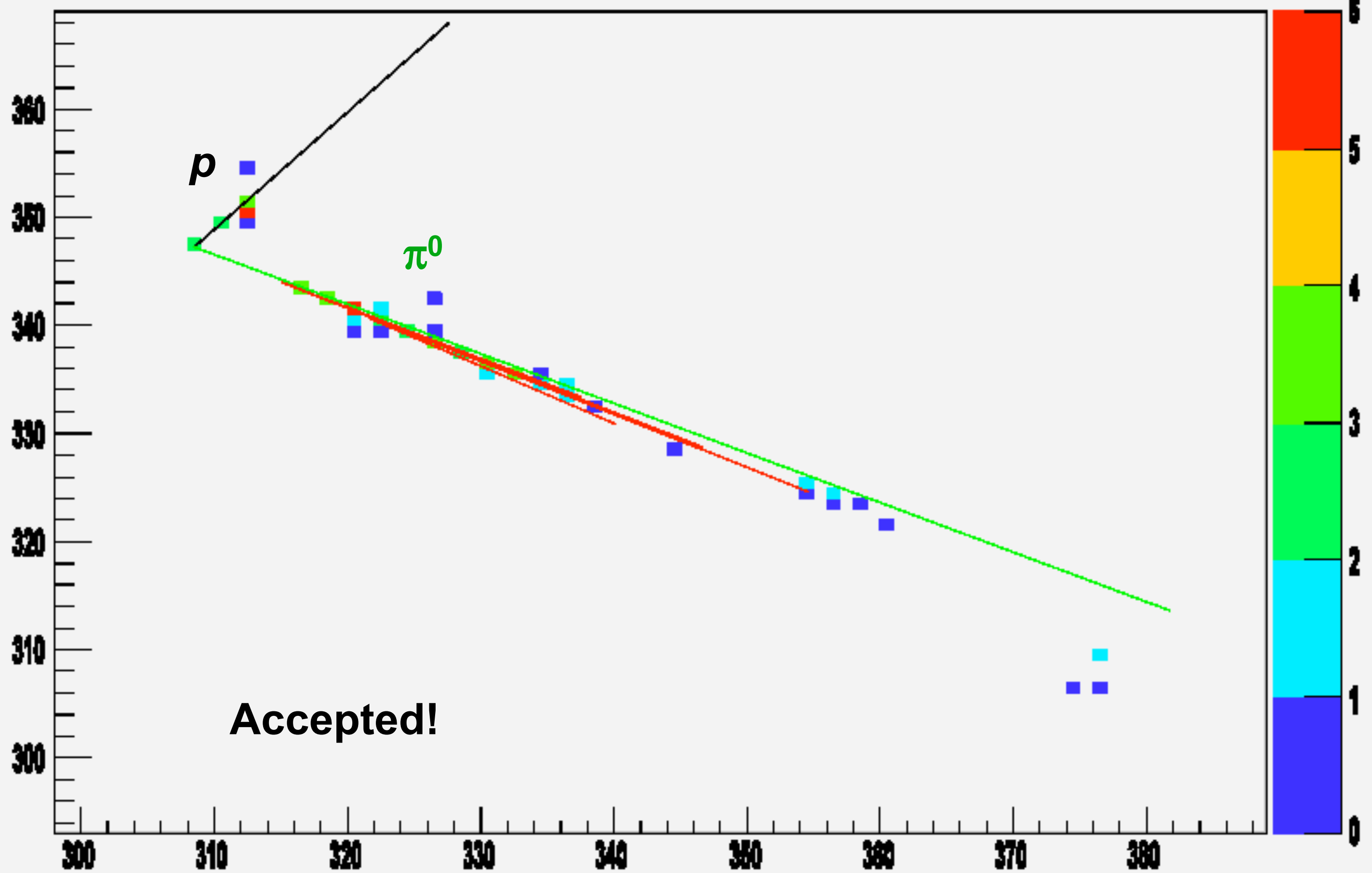




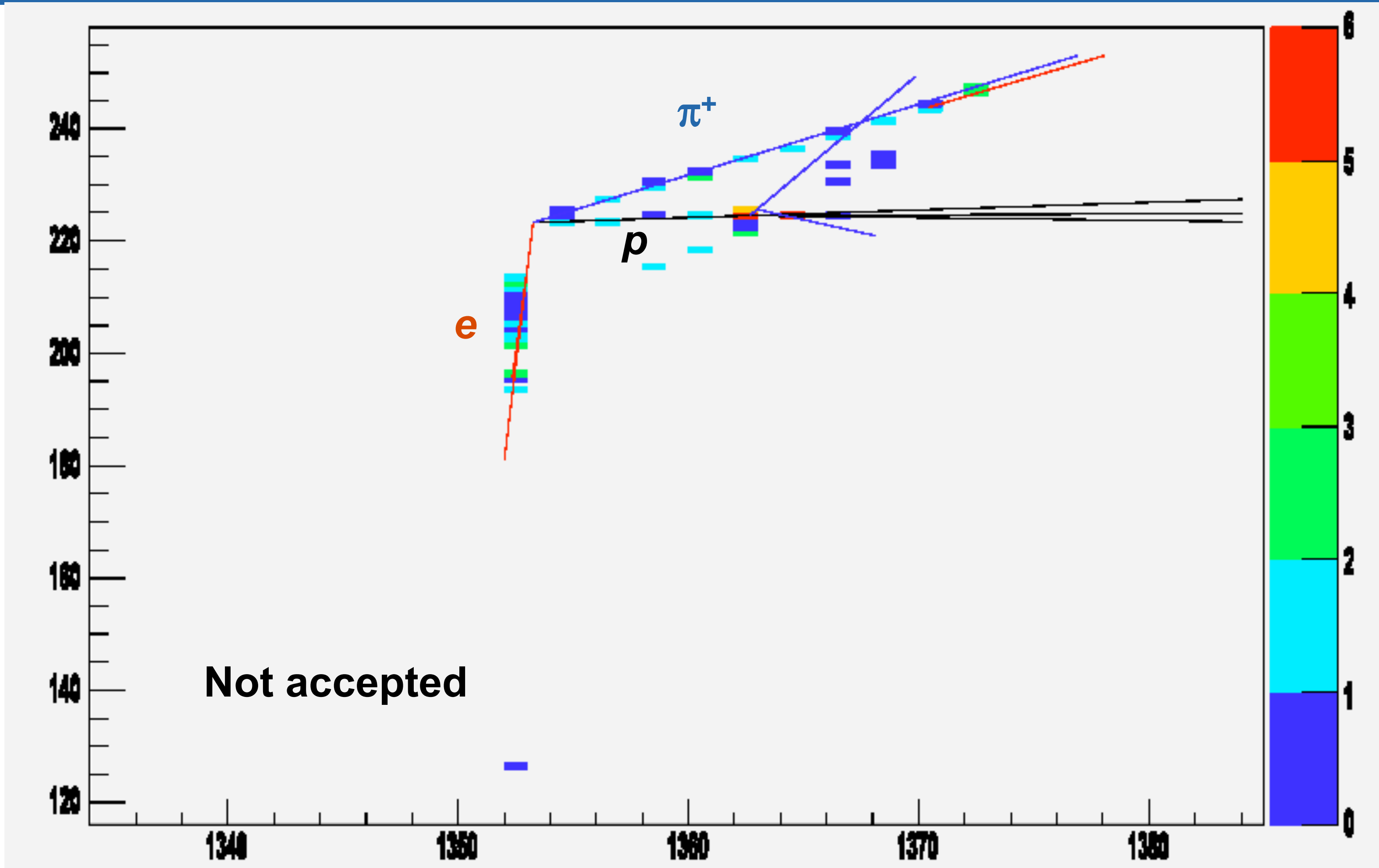
1.87 GeV $\nu_e N \rightarrow e p \pi^+ \pi^0$
x-z View



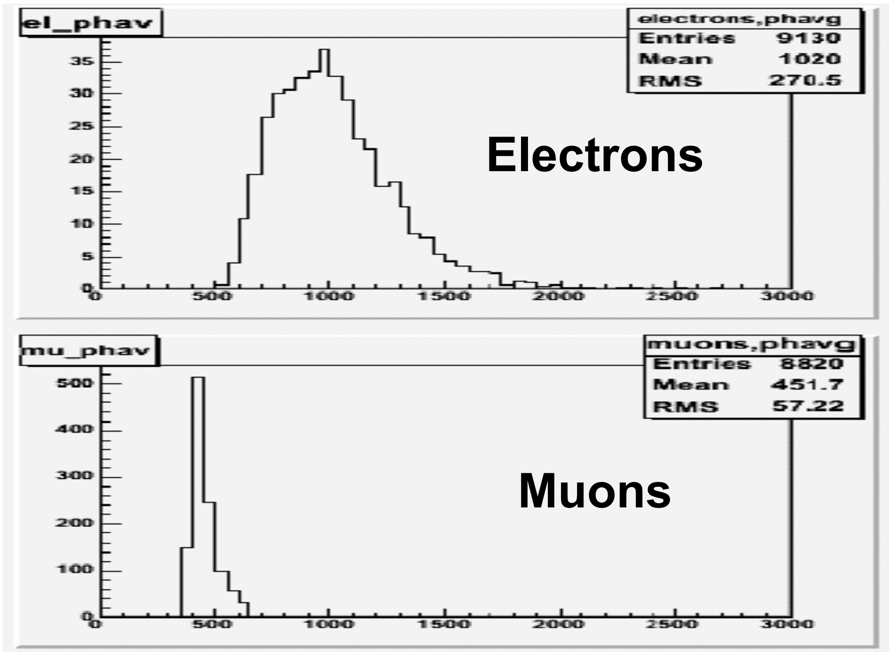
2.11 GeV $\nu_\mu N \rightarrow \nu_\mu p \pi^0$
x-z View



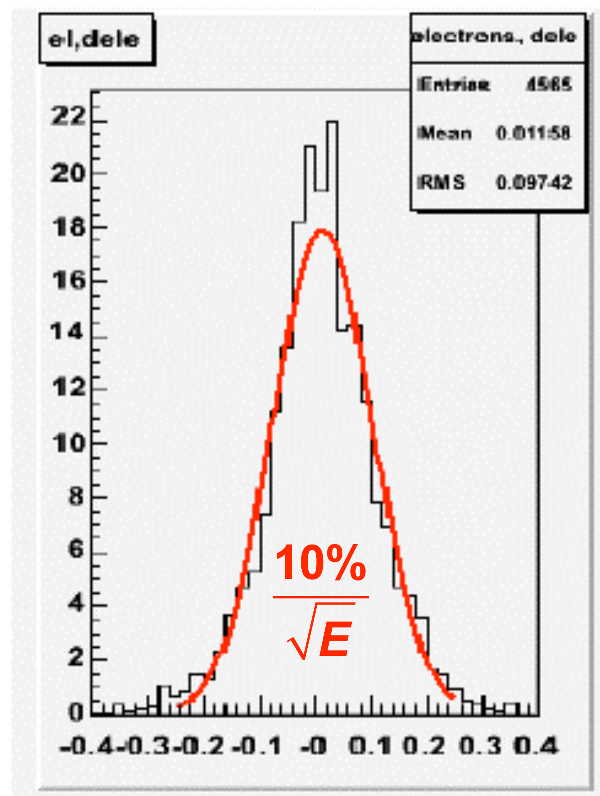
1.86 GeV $\nu_e N \rightarrow e p \pi^+$
x-z View



Electron ID and Resolution



Average pulse height per plane

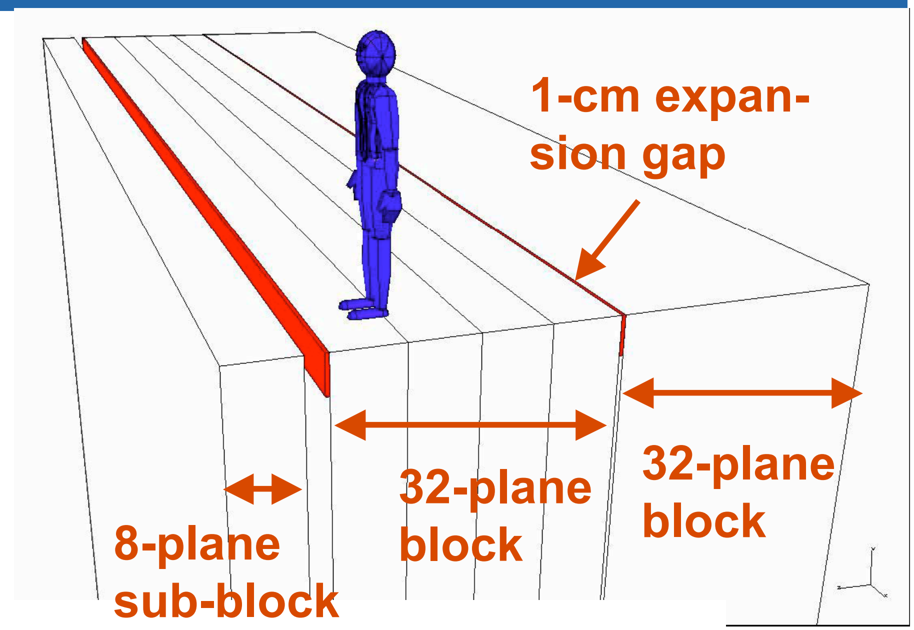


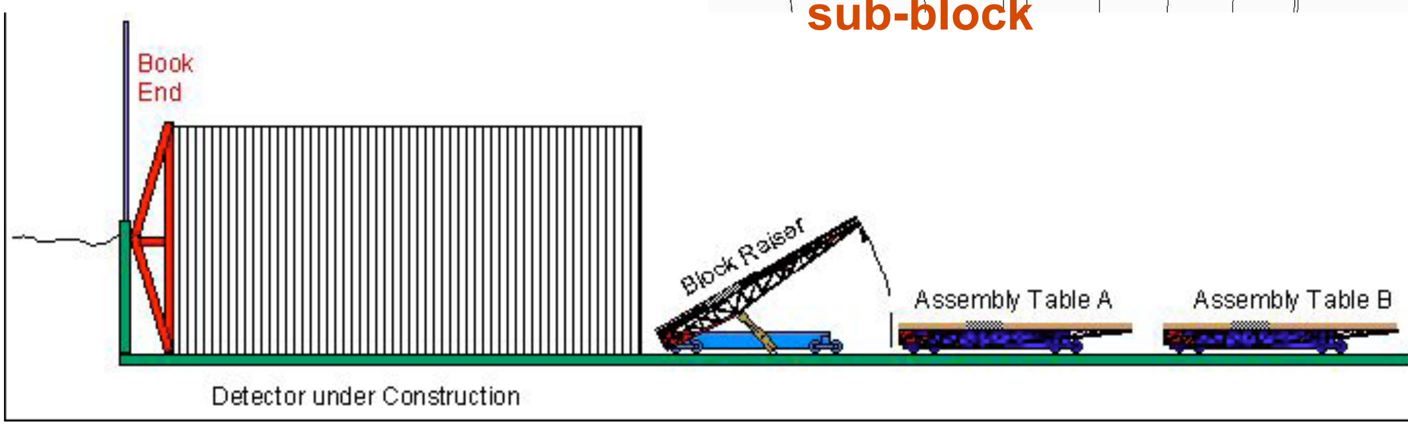
Electron resolution

Far Detector Assembly

One 8-plane sub-block assembled per day

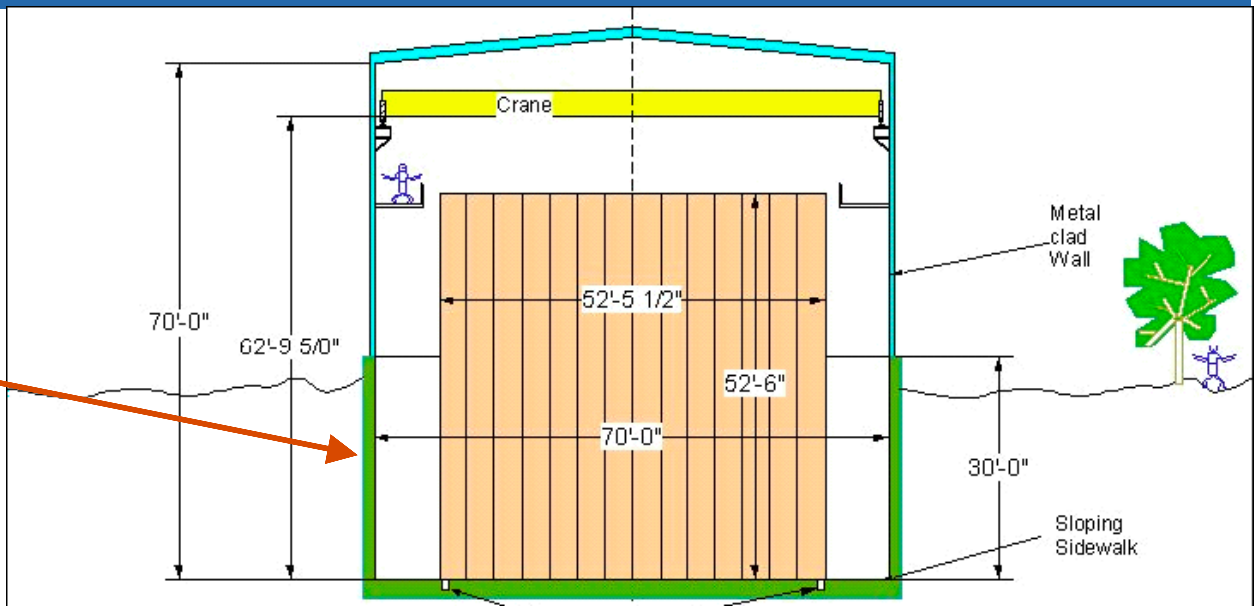
Detector has 248 sub-blocks

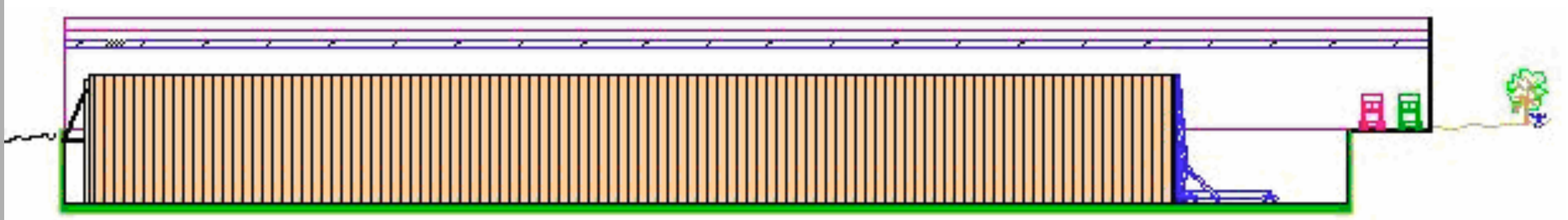




Far Detector Building
Proposal Design

Bathtub for full containment

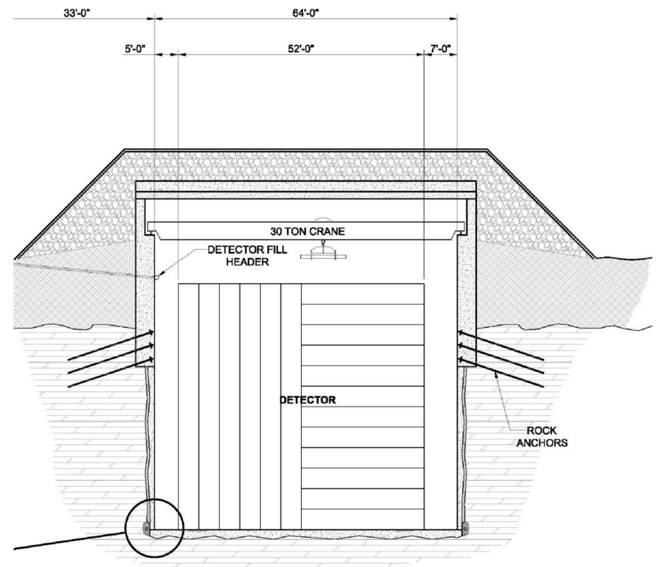


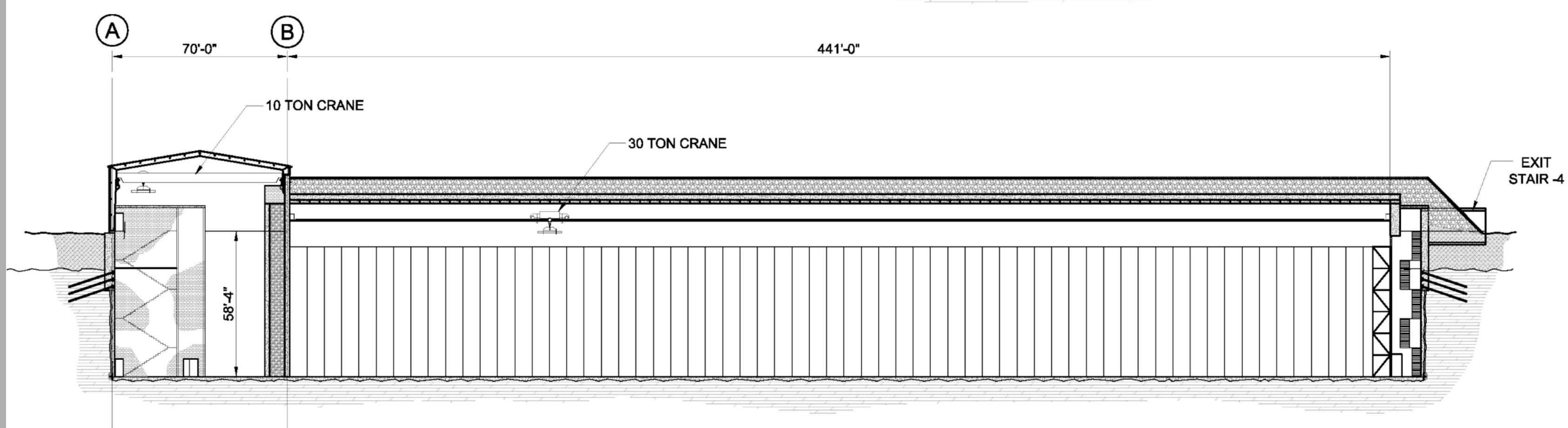


Far Detector Building

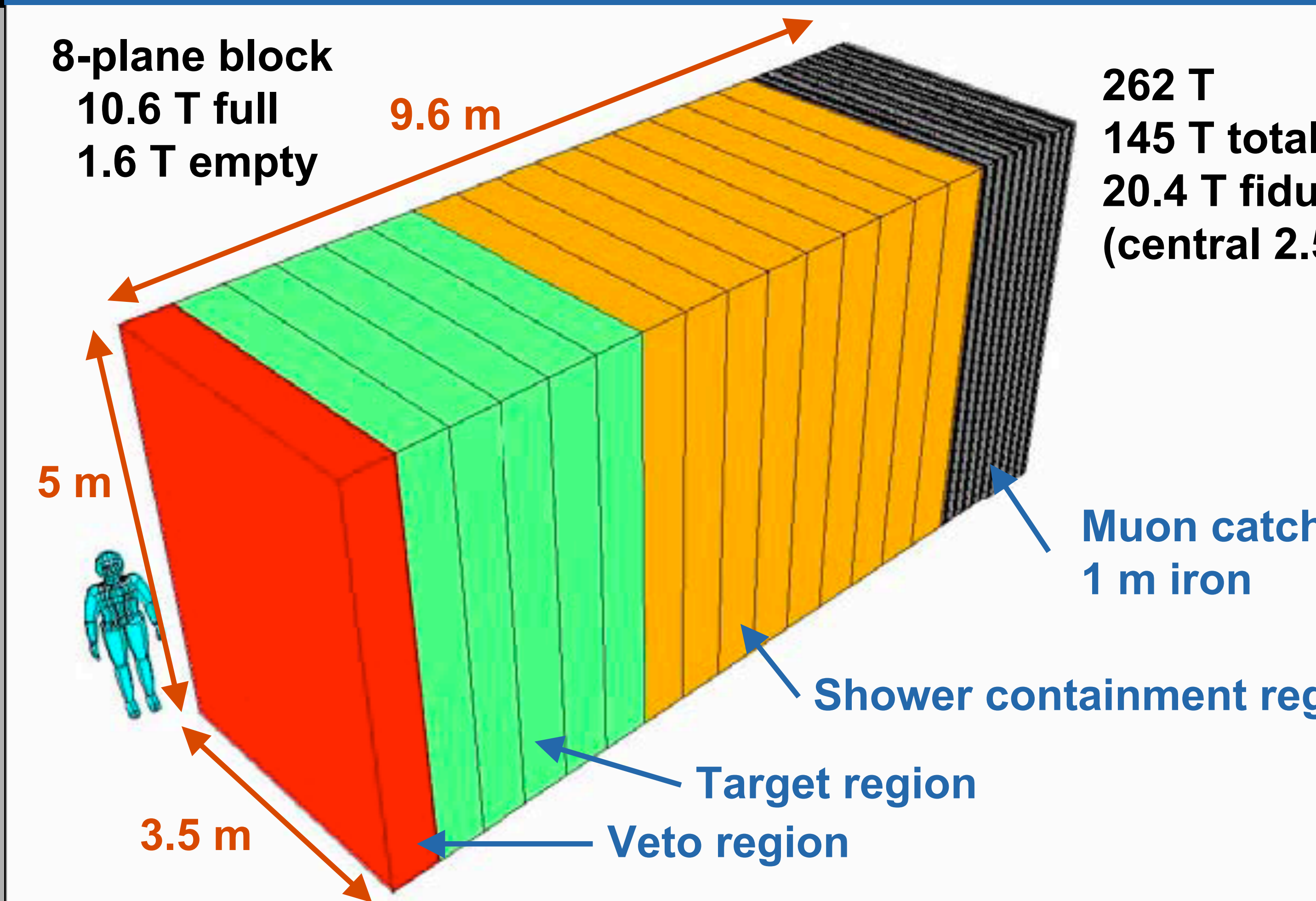
Design with Overburden

Current plan is to use overburden of a few meters

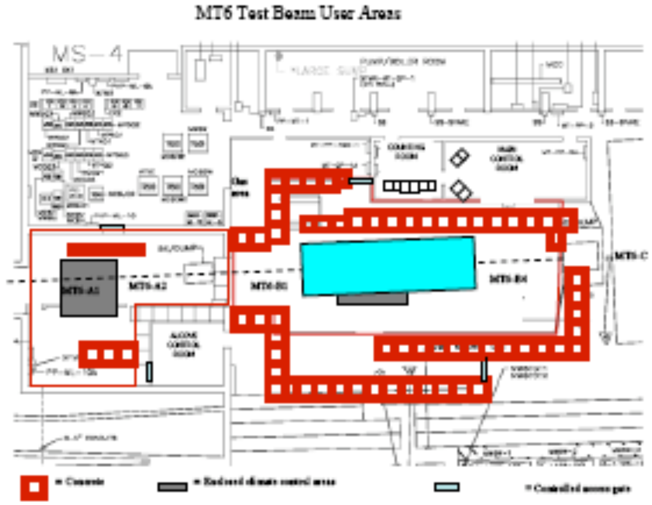




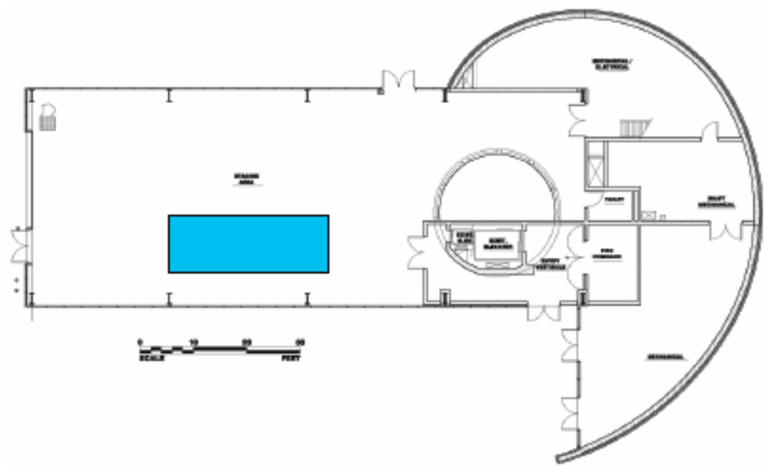
Near Detector



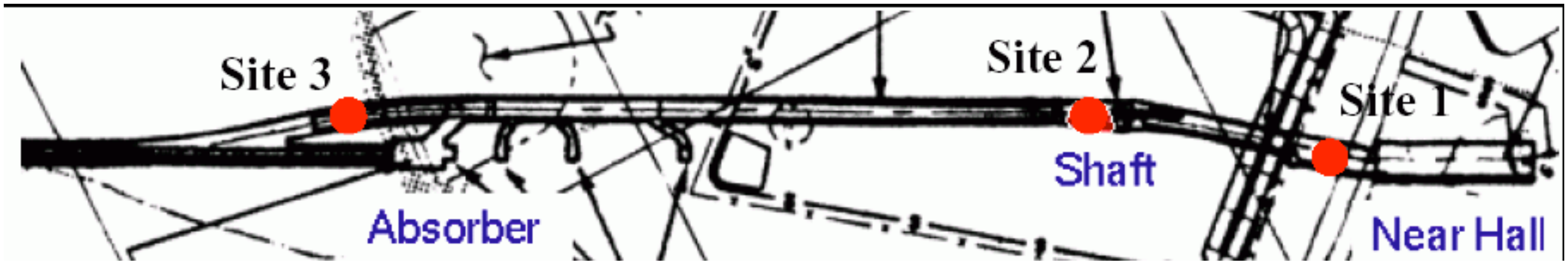
Near Detector: Modular and Mobile



M Test



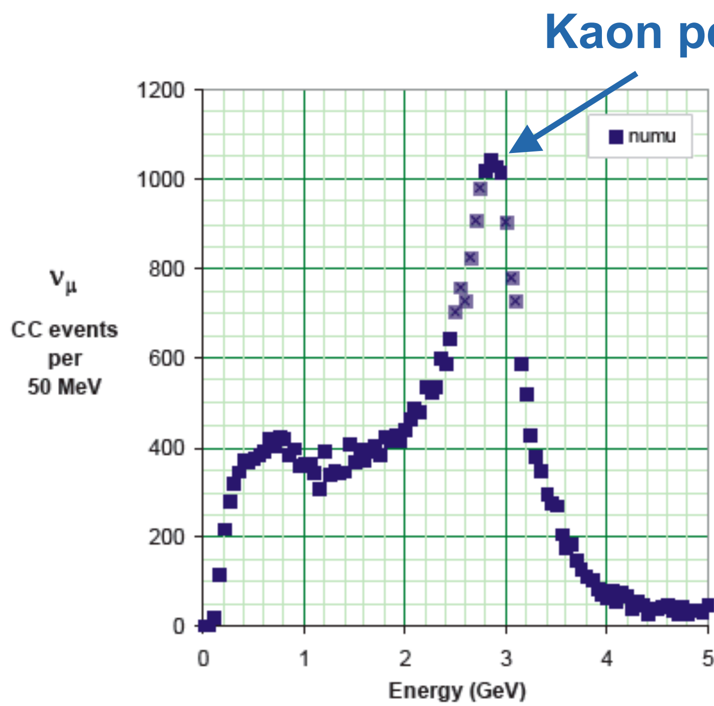
MINOS Surface Building



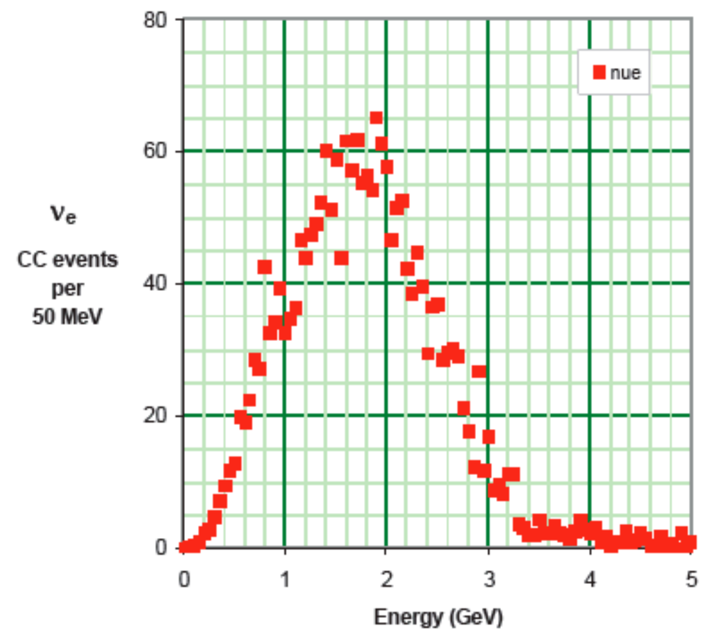
NuMI Access Tunnel

Near Detector in MINOS Surface Building

6.5 x 10^{20} pot in 75 mrad off-axis beam

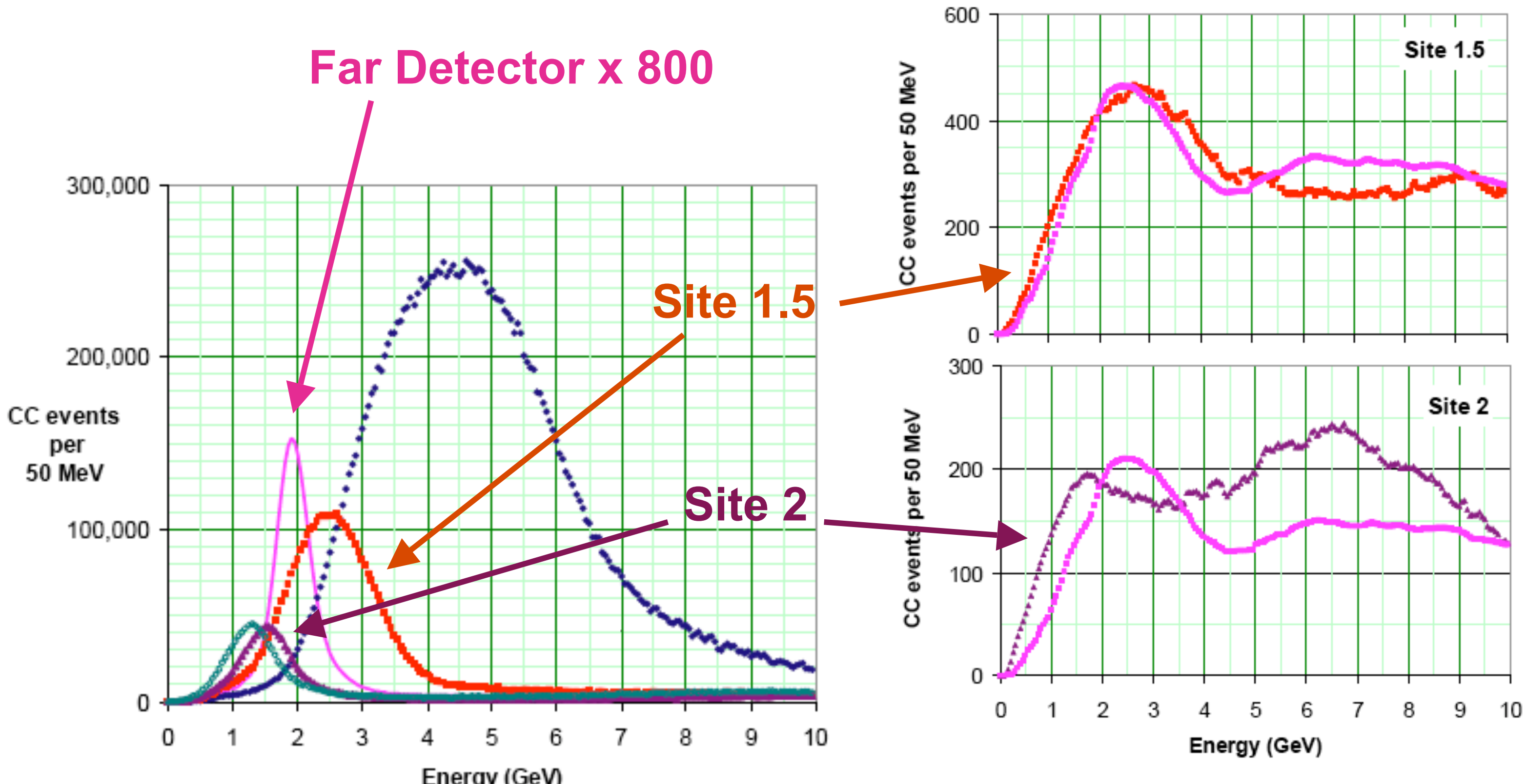


45,000 ν_μ CC events



2,200 ν_e CC events

Near Detector in the Access Tunnel



ν_μ CC events

ν_e CC events

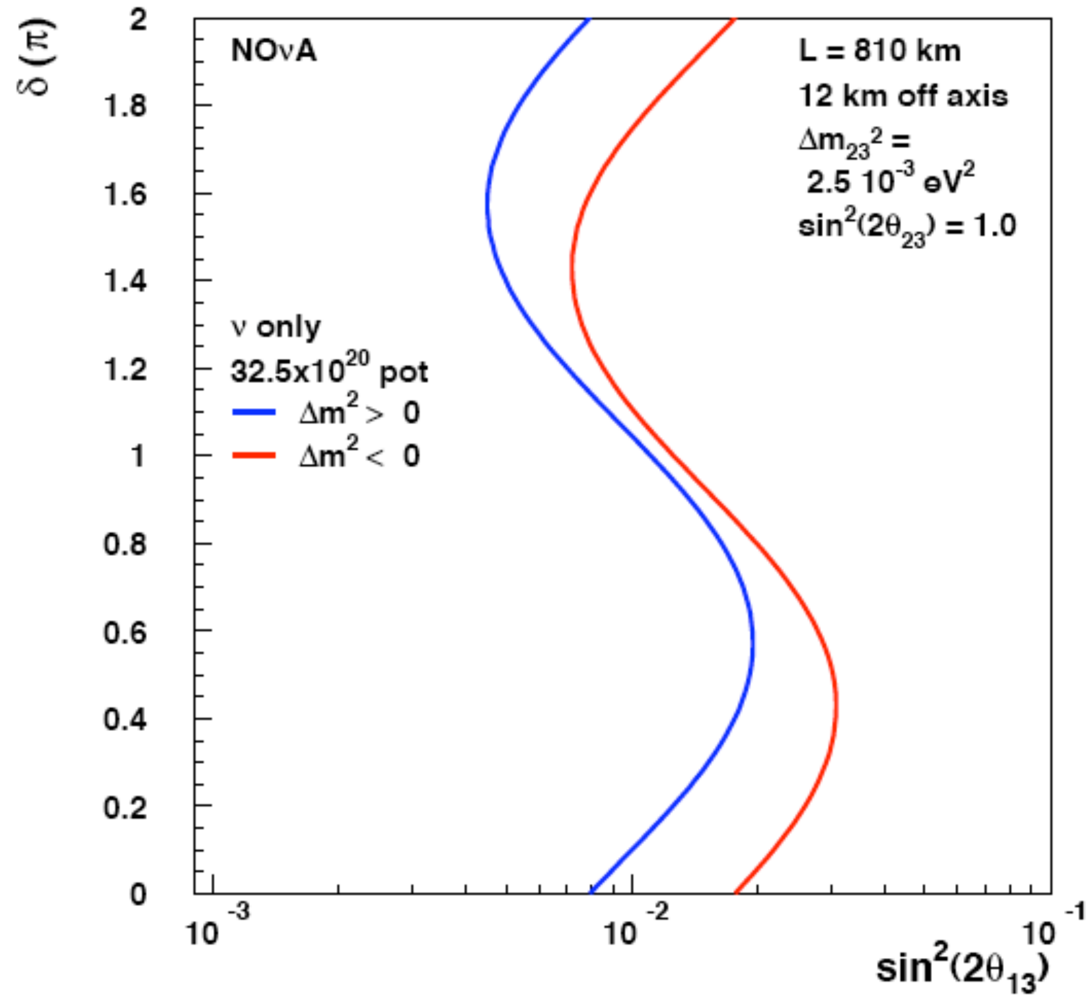
NOνA Prospects

- **The cancellation of the BTeV experiment caused a major change in the prospects for NOνA**
  - **Funds are available for medium size new initiatives**
  - **More protons are available**
- **DoE has signaled that it is prepared to put funds for NOνA in the FY07 budget**
  - **Pending NuSAG/P5 and OMB approval**
- **Strong Fermilab support**
  - **Only approved experiment in the post 2010 era**
- **DOE regulations regarding building construction may require the University of Minnesota to take a very active role with respect to the Far Detector building**

Post-Collider Proton Plan

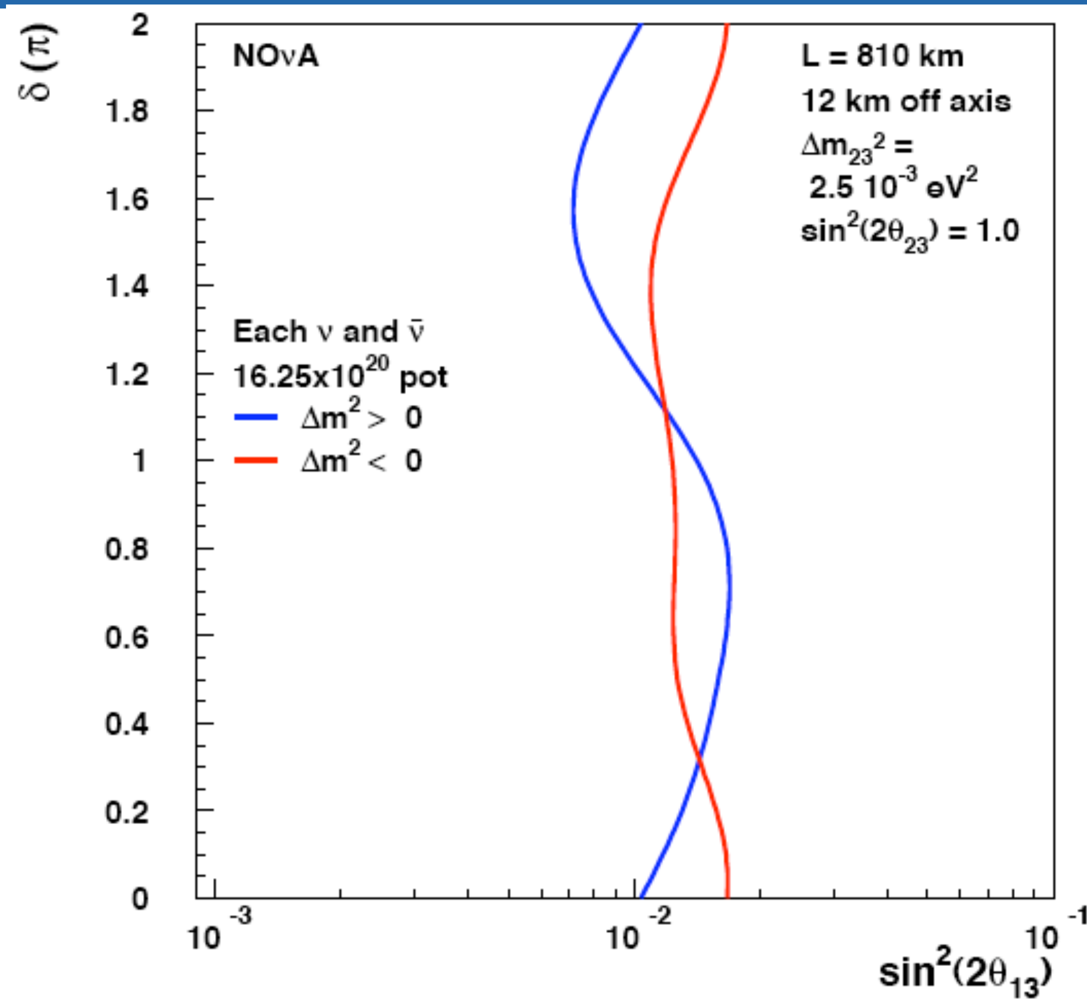
- **Proton Plan with Collider**
  - **9/11 Slip-stacked Booster batches at 5.5×10^{12} p/batch**
  - **Repetition rate = 0.8 s (Booster) + 1.4 s (Ramp) = 2.2 s**
  - **10% for Collider shot setup + 5% for antiproton transfer**
  - **$\Rightarrow$ 3.4×10^{20} protons/yr**
- **Post-Collider Proton Plan**
  - **11 batches for neutrinos $\Rightarrow$ 11/9 = 1.22 factor**
  - **Hide Booster filling time in Recycler $\Rightarrow$ 0.8 s $\rightarrow$ 0.067 s $\Rightarrow$ 2.2 s $\rightarrow$ 1.467 s = 1.50 factor**
  - **Save 10% shot setup and 5% antiproton transfer = 1.17 factor**
  - **$\Rightarrow$ (3.4×10^{20} protons/yr)(1.22)(1.50)(1.17) = (7.3×10^{20} protons/yr)**
- **Negotiated rate is 90% of this: (6.5×10^{20} protons/yr)**
- **Proton Driver rate taken as 25×10^{20} protons/yr**
- **Fermilab is developing Proton Driver alternatives that might provide ~1/2 flux for a few times 10^7 dollars**

3 σ Sensitivity to $\theta_{13} \neq 0$



5 year
ν only
run

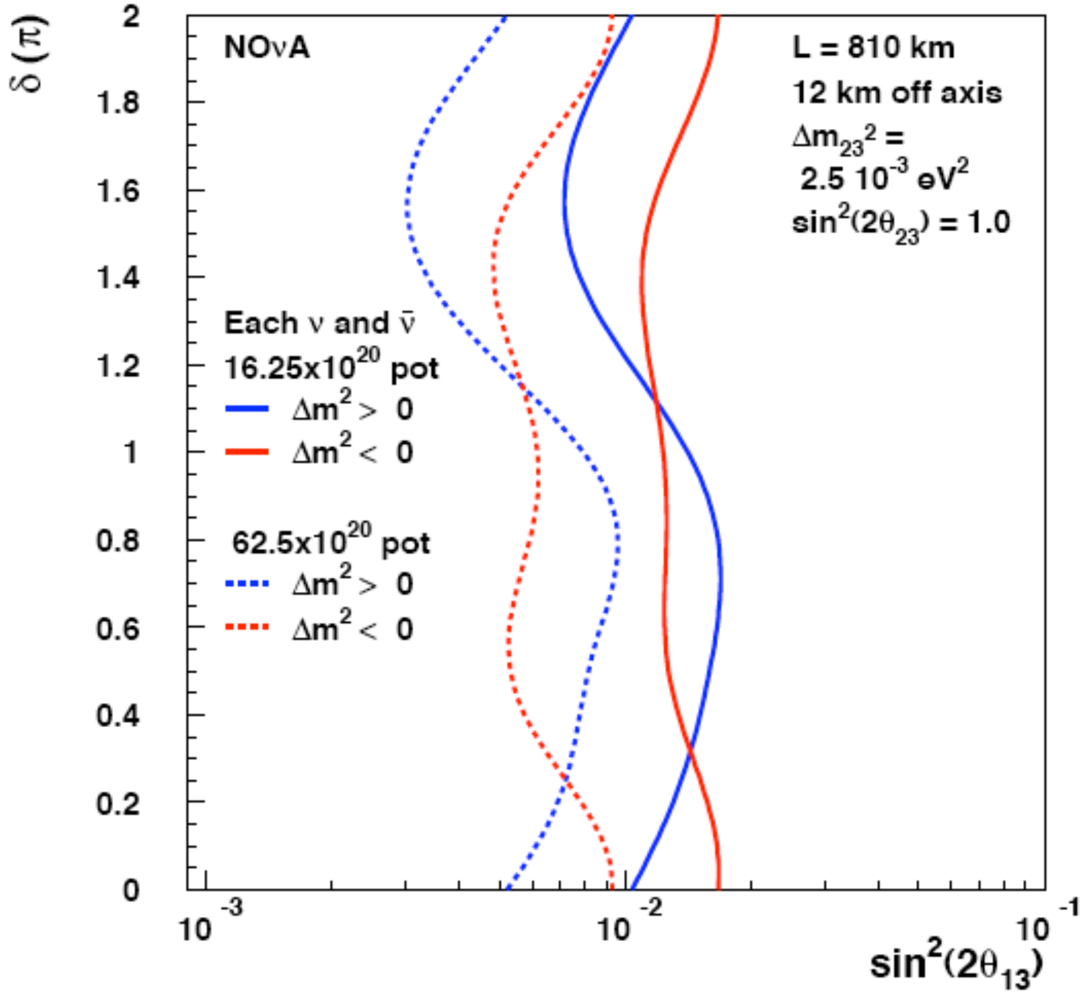
3 σ Sensitivity to $\theta_{13} \neq 0$



2.5 yr each

ν and ν̄ run

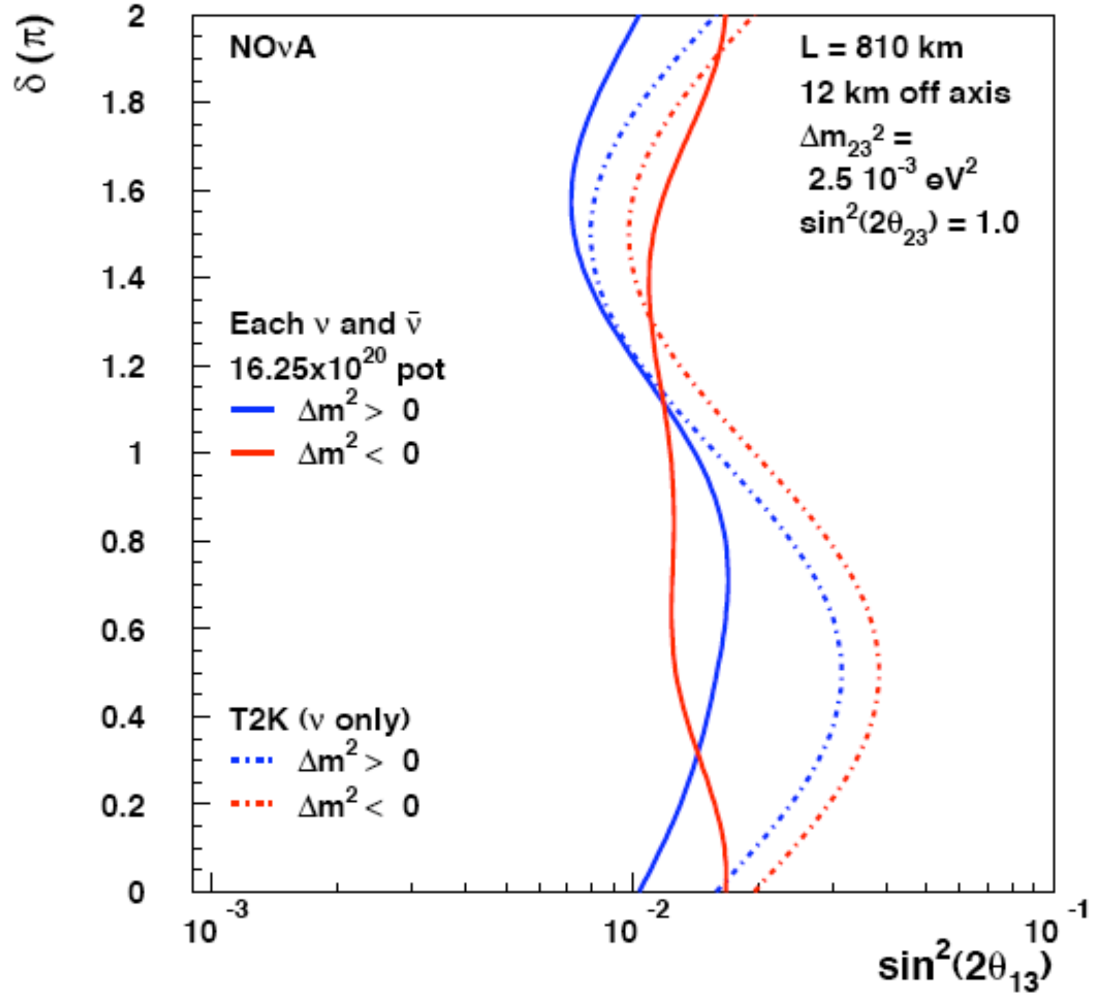
$3\ \sigma$ Sensitivity to $\theta_{13} \neq 0$
Comparison with Proton Driver



2.5 yr each

ν and $\bar{\nu}$ run

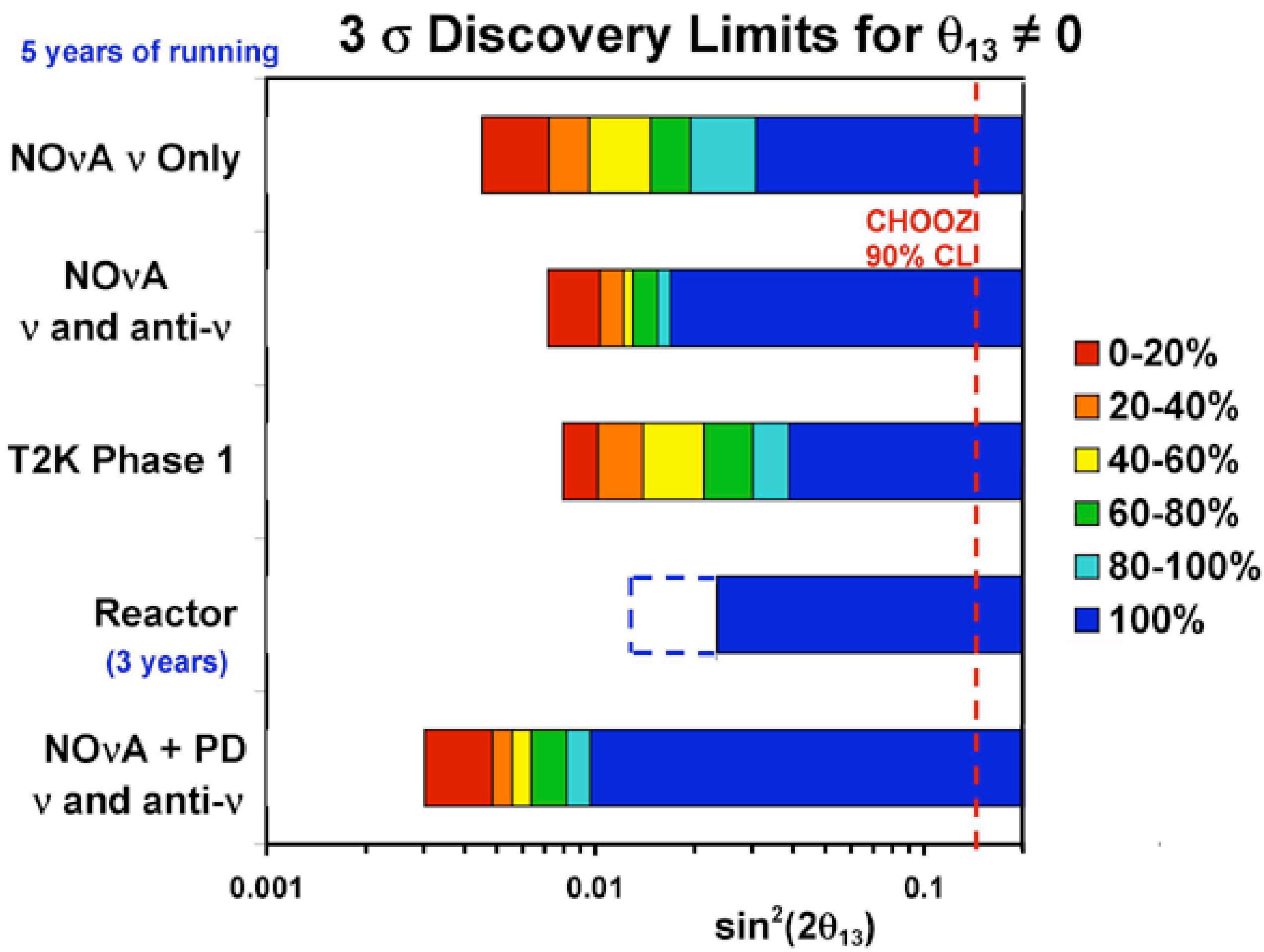
3 σ Sensitivity to $\theta_{13} \neq 0$



2.5 yr each

ν and $\bar{\nu}$ run

3 σ Sensitivity to $\theta_{13} \neq 0$



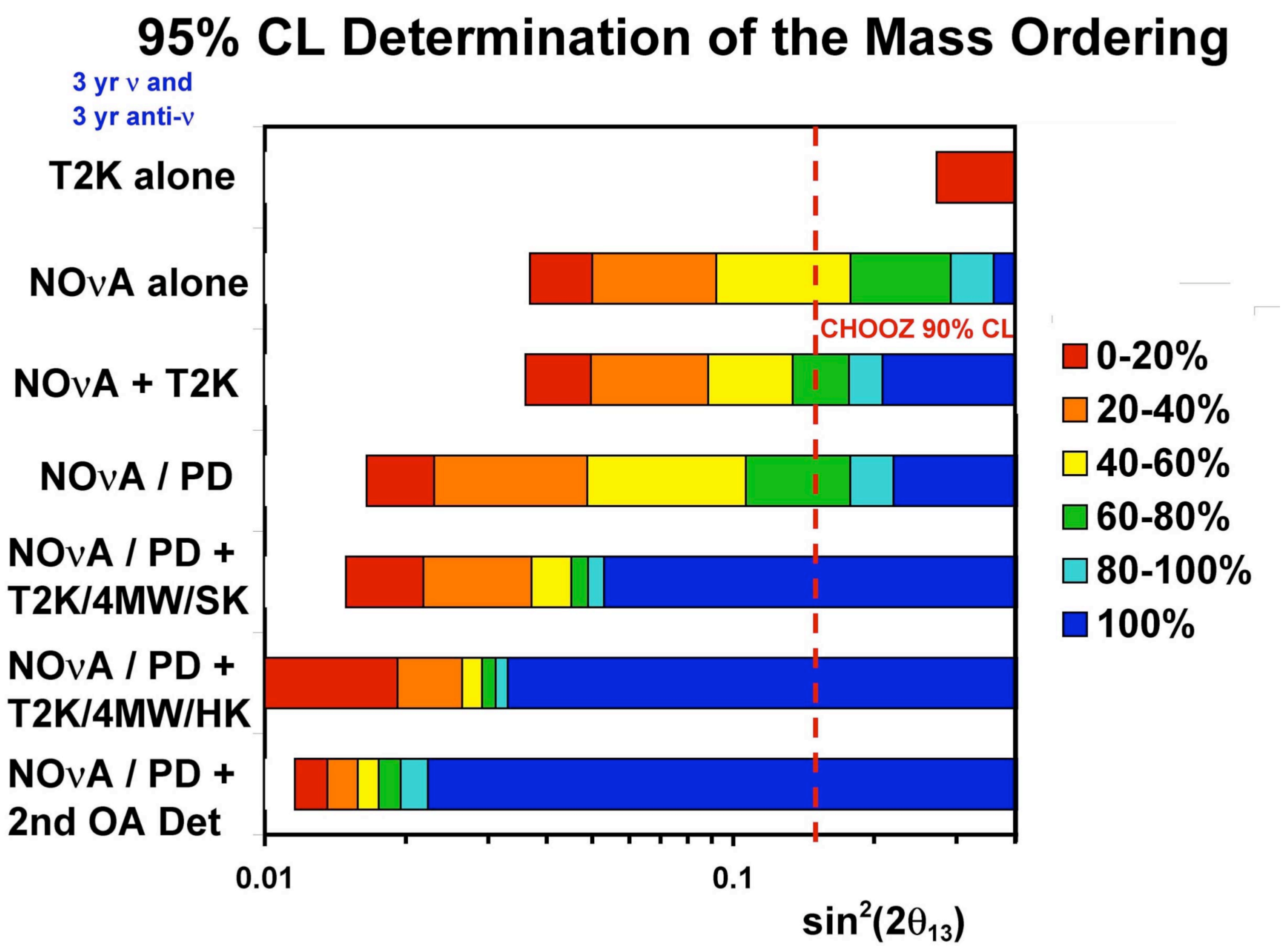
Importance of the Mass Ordering

- **Window on very high energy scales: grand unified theories favor the normal mass ordering, but other approaches favor the inverted ordering.**
- **If we establish the inverted ordering, then the next generation of neutrinoless double beta decay experiment can decide whether the neutrino is its own antiparticle. However, if the normal ordering is established, a negative result from these experiments will be inconclusive.**
- **To measure CP violation, we need to resolve the mass ordering, since it contributes an apparent CP violation that we must correct for.**

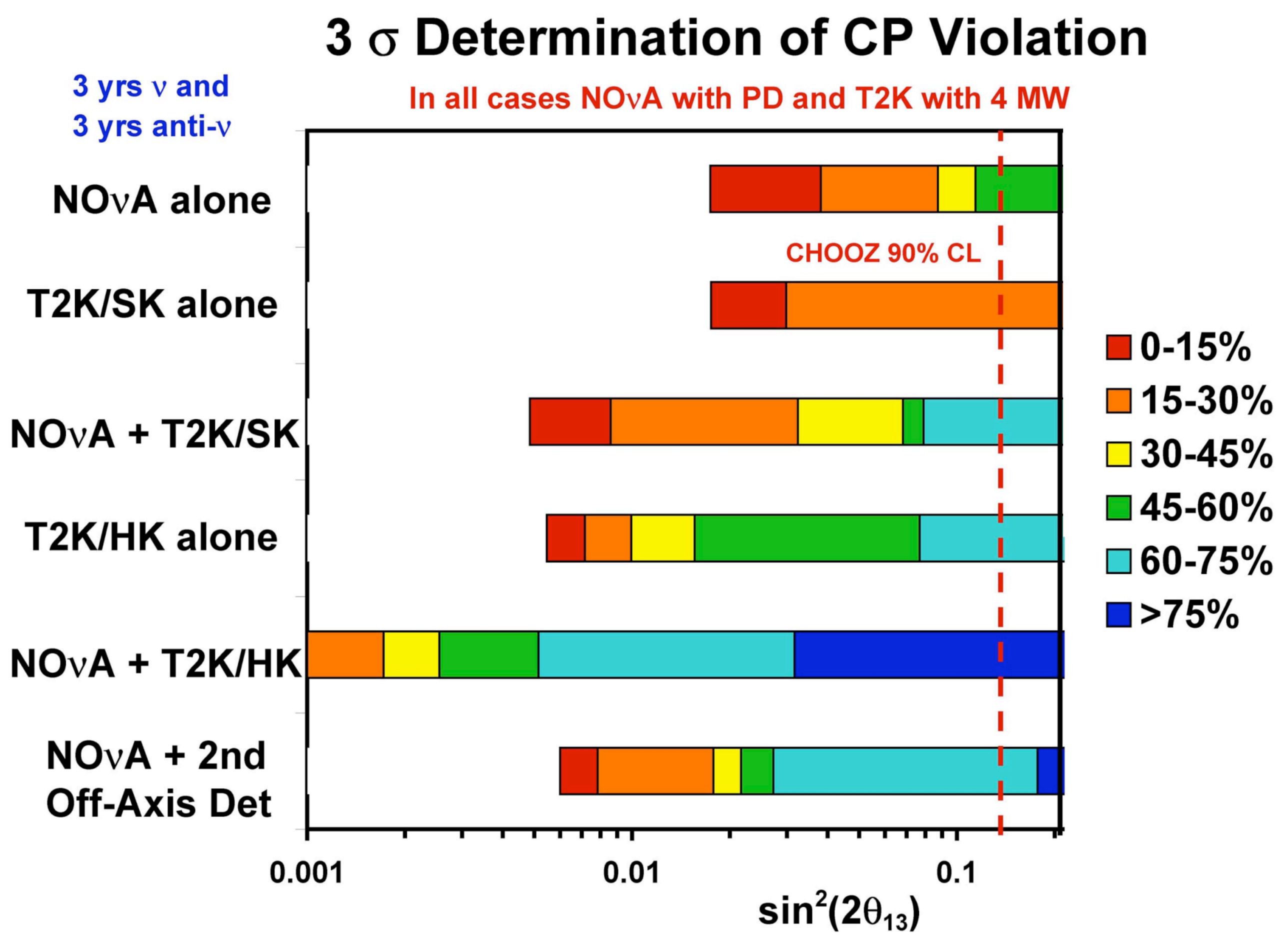
Role of NOνA in Resolving the Mass Ordering

- The mass ordering can be resolved only by matter effects in the earth over long baselines.
- NOνA is the only proposed experiment with a sufficiently long baseline to resolve the mass ordering.
- The siting of NOνA is optimized for this measurement.
- NOνA is the first step in a step-by-step program that can resolve the mass ordering in the region accessible to conventional neutrino beams.

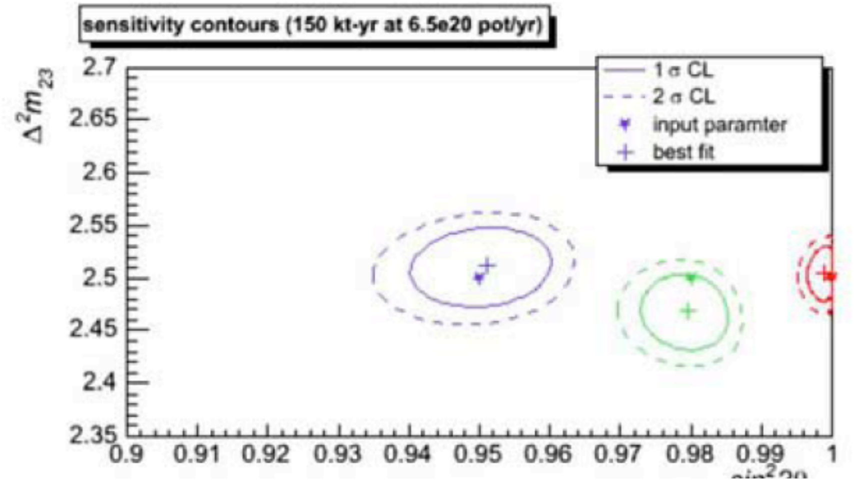
95% CL Resolution of the Mass Ordering



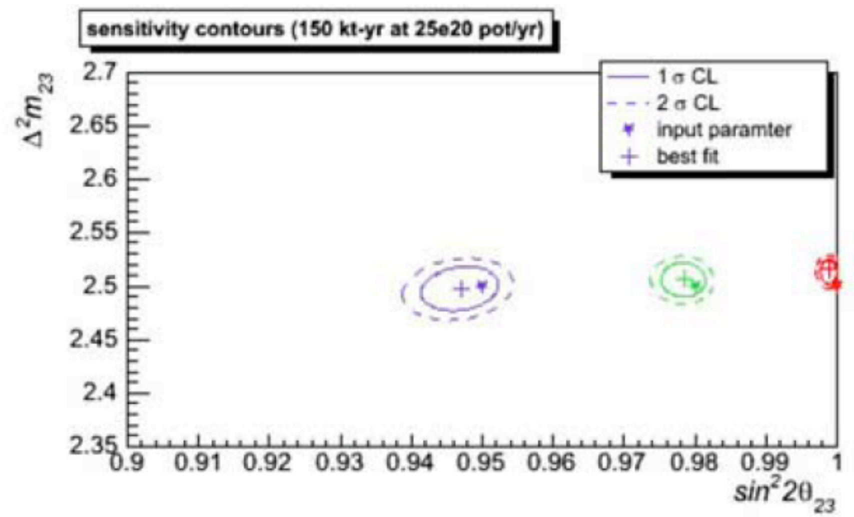
3 σ Determination of CP Violation



Measurement of Δm_{32}^2 and $\sin^2(2\theta_{23})$

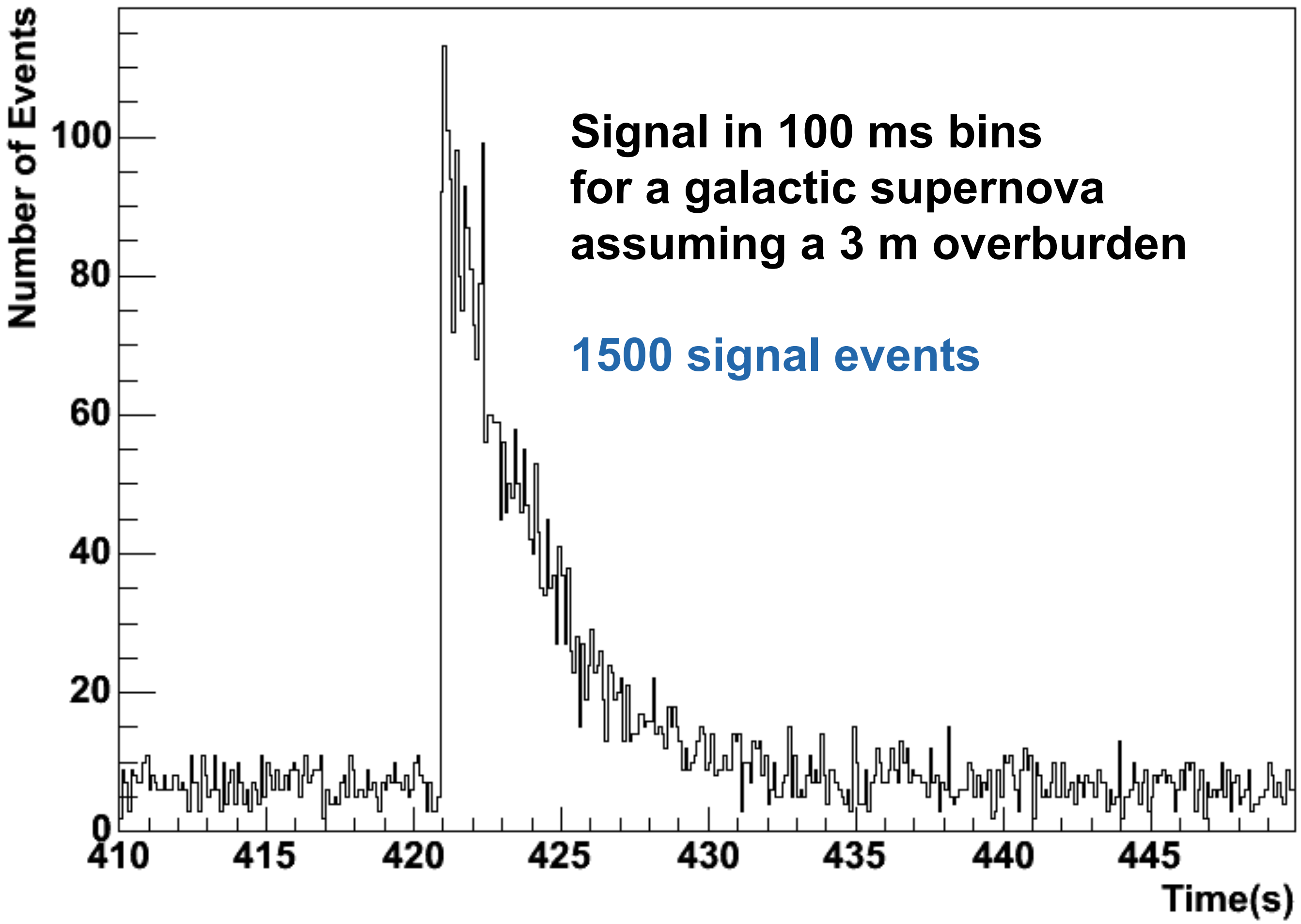


5-year ν run



5-year ν run
with Proton Driver

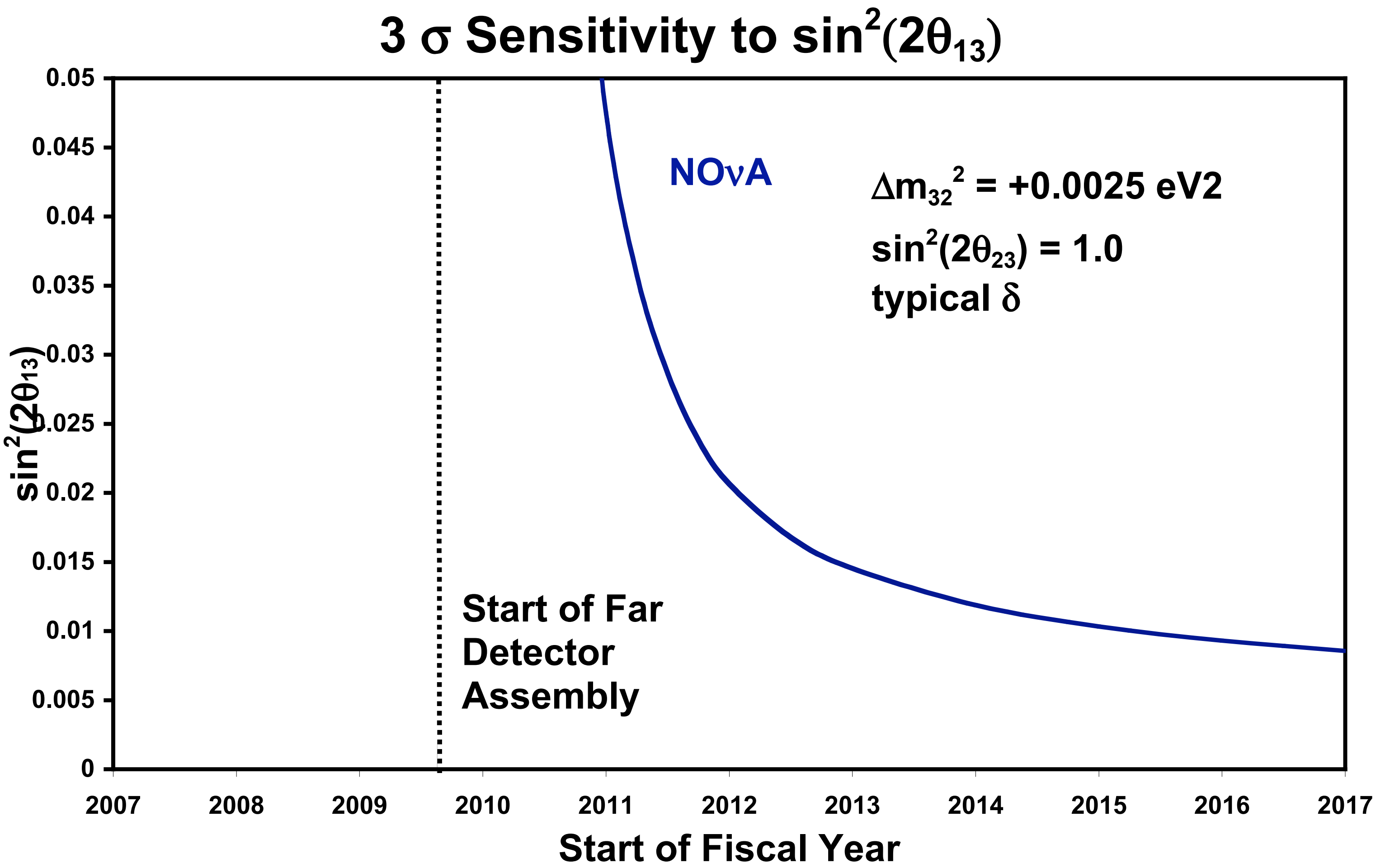
Sensitivity to a Galactic Supernova



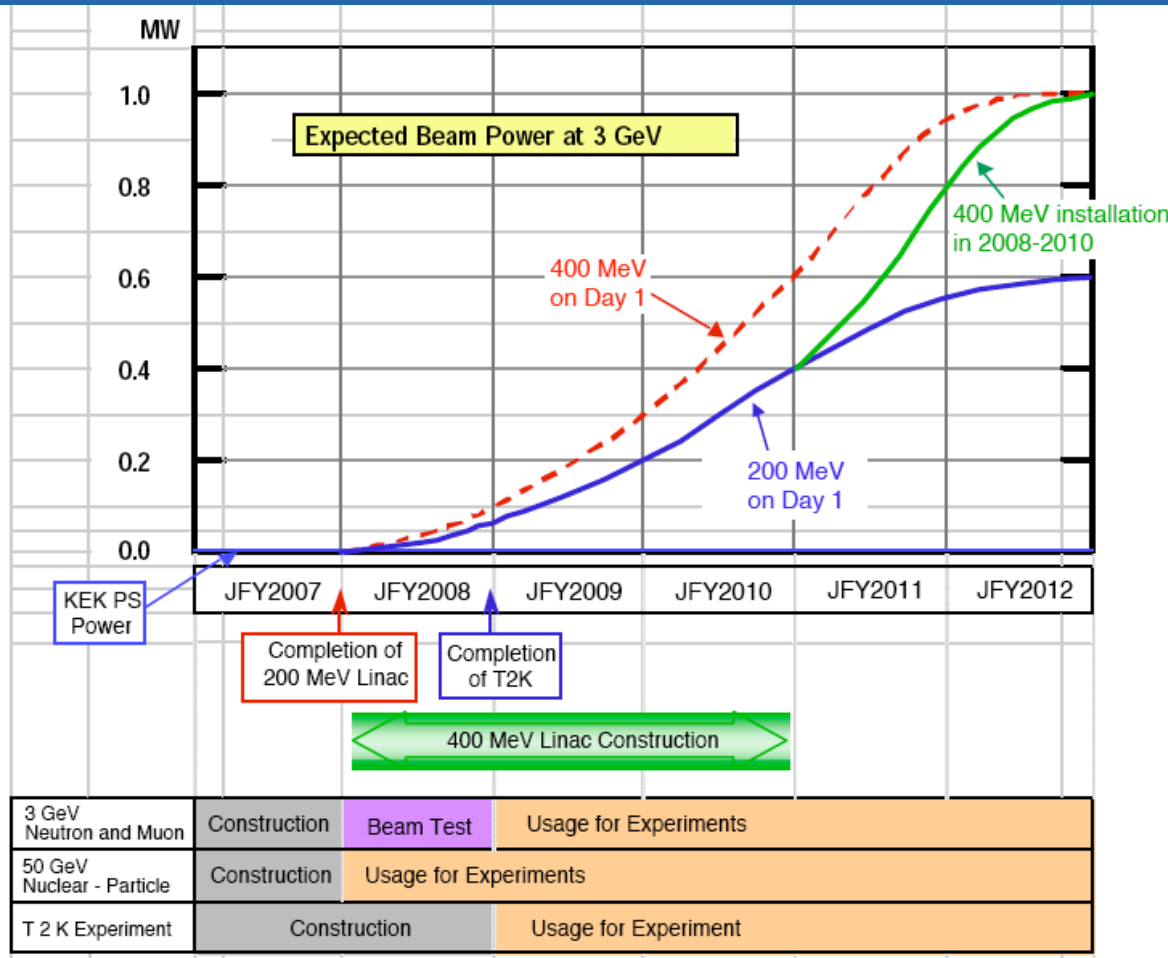
Schedule
(10 of 29 Milestones)

Project start	Oct 2006
R&D prototype Near Detector complete	Mar 2007
Start Far Detector Building construction	Jul 2007
Start receiving packaged APDs	Oct 2007
Start extrusion module factories	Oct 2007
Start construction of Near Detector	Dec 2007
Start operation of Near Detector	Jul 2008
Start Far Detector assembly	May 2009
First kiloton operational	Oct 2009
Full 30 kilotons operational	Jul 2011

Sensitivity vs. Time

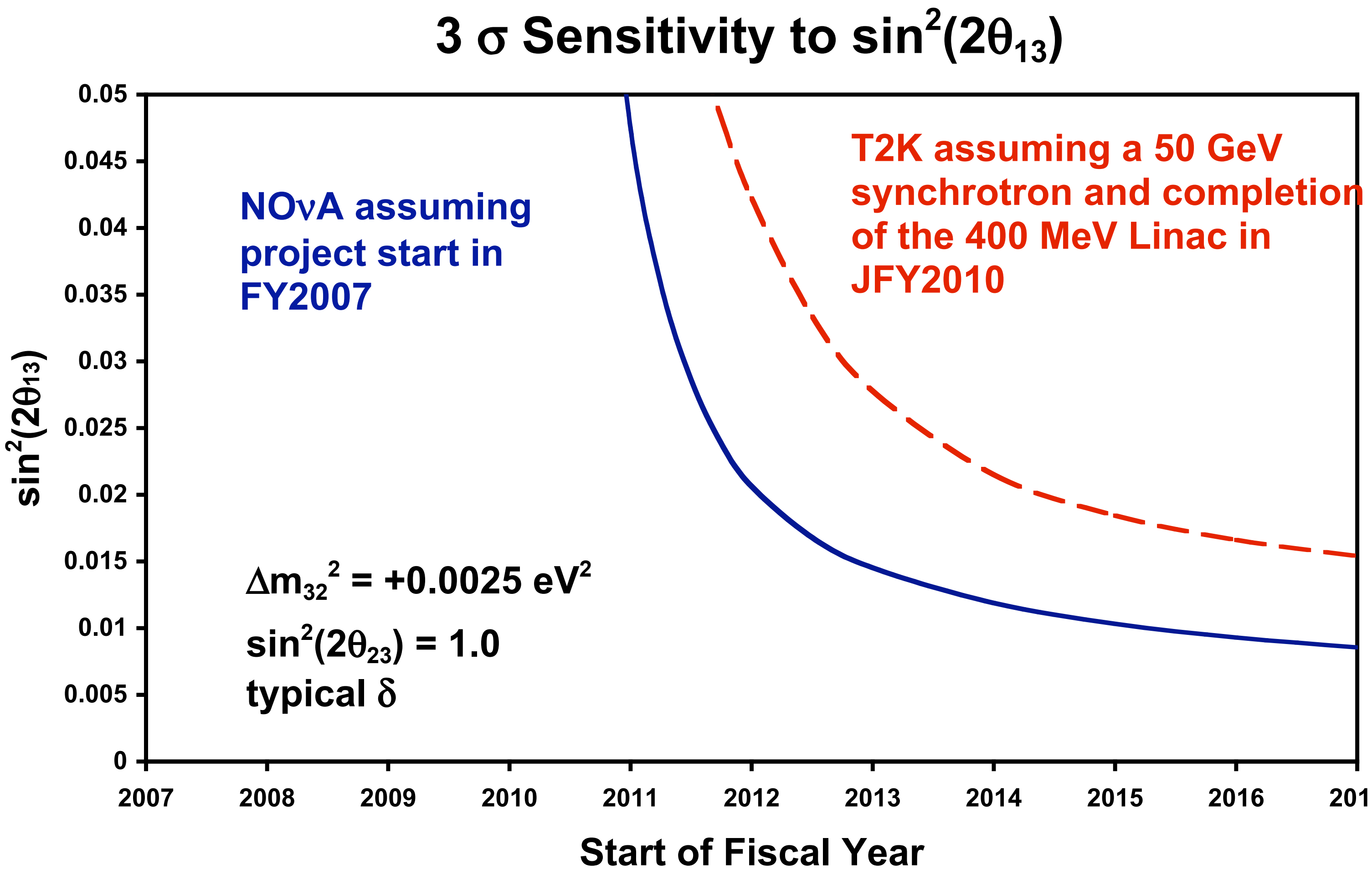


Assumed T2K Beam Power vs. Time



From S. Nagamiya, Feb 2005

Sensitivity vs. Time
Comparison to T2K



Conclusion

- NOνA provides a flexible approach to studying all of the parameters of neutrino oscillations
  - A long baseline approach is crucial in the context of the world program.
  - NOνA is the first stage of a flexible program where each stage can be planned according to what has been learned in previous stages.
  - The NOνA physics reach is greater than other experiments being contemplated for the next few years.
  - The full range of the NOνA/NuMI program is comparable to that of other conventional approaches.
  - NOνA is the size project that can be started now.